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Accuracy and precision of suspended sediment loads

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ABSTRACT The effects of five computational methodologies and four sampling frequencies on the accuracy and precision of annual suspended sediment load estimates have been explored. The mean ratio of the estimated annual suspended load to the population suspended sediment load has been determined for each method and frequency as an index of accuracy. The standard deviation of the ratio has been determined as an index of precision. Some computational methods have been found to be both precise and accurate over a range of sampling frequencies. One method appears to be reasonably precise but very inaccurate; another reasonably accurate but not precise. The results are seen to be extremely important for the selection of both sampling schemes and computational techniques for suspended sediment studies, and for the evaluation of existing data sets.

Exactitude et précision des estimations du débit solide des cours d'eau
RESUME L'influence de cinq méthodes de calcul et de quatre fréquences d'échantillonnage sur l'exactitude et la précision des estimations des charges annuelles en suspension a été étudiée. Le rapport moyen de l'estimation de la charge annuelle en suspension à la charge en suspension de la population a été déterminé pour chaque méthode et chaque fréquence et a servi d'index d'exactitude. La déviation standard de ce rapport a servi d'index de précision. Certaines méthodes de calcul sont à la fois précises et exactes pour diverses fréquences d'échantillonnage. Une des méthodes apparaît raisonnablement précise mais est très inexacte; une autre est raisonnablement exacte mais imprécise. Ces résultats sont extrêmement importants quant à la sélection des méthodes d'échantillonnage et de calcul pour l'étude de la charge en suspension et l'évaluation des résultats déja existant.

INTRODUCTION

Knowledge of suspended sediment loads in rivers has become increasingly important and necessary in recent years. There has been much concern regarding not only the siltation of streams and reservoirs but also sediment as a potential carrier of pollutants into systems such as the Great Lakes of North America (PLUARG, 1978). The need for sediment load information for decision making in these matters has caused the number of routine and project-oriented monitoring systems to escalate dramatically. With this surge in activity has also come a greater interest in the accuracy of suspended sediment and other pollutant loadings (Rast & Gregor, 1979; Sanzogni *et al.*, 1979).

The interest in accuracy stems from a need for better data to aid in more critical decision making, and from a realization that suspended sediment data can be grossly in error. Walling (1977) has noted that annual sediment loads can be overestimated by as much as 30% and errors in estimation of monthly loads can vary between +900% and -80%. Kleiber & Erlebach (1977) have reported that loading estimates are biassed, as well as imprecise, when suspended sediment concentrations are sparsely sampled and used as estimates of mean monthly or quarterly concentrations. Significant effects of sampling frequency on the accuracy of several types of mass discharge estimates have also been demonstrated by Weber *et al.* (1979). Hore & Ostry (1978) have noted that differences in unit area load estimates of suspended solids may be as great as 300% due to computational procedures alone.

For sediment estimates to provide useful input for decisions regarding siltation and pollution, it is now evident that such factors as sampling frequencies and computational strategies must be more carefully evaluated. There is a need for methodologies for ascertaining the accuracy and precision of suspended sediment data. This paper provides an approach to the indexing of accuracy and precision, and demonstrates the utility of such indices for an examination of the effects of selected computational methodologies and sampling frequencies. The annual suspended sediment load estimates for Big Otter Creek in Ontario, Canada, have been selected to illustrate the approach.

STUDY LOCATION

Since the relative affects of computational methods and sampling frequencies are linked to the hydrological and sediment regimes being studied, a brief note regarding these aspects of the study area are included.

Big Otter Creek is located at approximately 42°51'N and 80°36'W in the Lake Erie basin, Ontario. The stream flows generally southward as it drains predominantly agricultural land situated on a sand plain and a series of glacial end moraines.

The regional climate is subhumid continental with moderate winters and warm summers. The mean daily temperature in January is -4.4°C, while for July it is 21.1°C. The mean annual precipitation of 890 mm is quite uniformly distributed throughout the year, although it occurs as snow during the winter months from December to March (mean annual snowfall is 122 cm), and short duration rainfall intensities during the summer months from June to September are 2.5 to 3.0 times greater than those in the spring and fall (Dickinson, 1977).

The annual flow regime is typical of basins in the area. Big Otter Creek is a perennial stream with greatest flows during the spring period resulting from snowmelt, rain on snow, and rainfall on bare soil. Summer flows are characteristically low, emanating from groundwater discharge and return flow from irrigation in the tobacco fields. Occasionally, small volume runoff events occur during the summer as a result of heavy localized thunderstorm activity.

The temporal pattern of the suspended sediment regime has been described in the literature (Dickinson *et al.*, 1975; Dickinson & Wall, 1977). Daily suspended sediment loads for Big Otter Creek exhibit a highly skewed frequency distribution, the mean load being equalled or exceeded less than 20% of the time. The seasonal pattern reveals that more than 70% of the annual load transport occurs during the months of February to May (Fig. 1). This pattern closely parallels the seasonal distribution of flood occurrences in the area with 60% of the annual extreme floods occurring in March and April (Dickinson, 1972).

ANALYSIS OF METHODS AND FREQUENCIES

The accuracy and precision associated with the application of

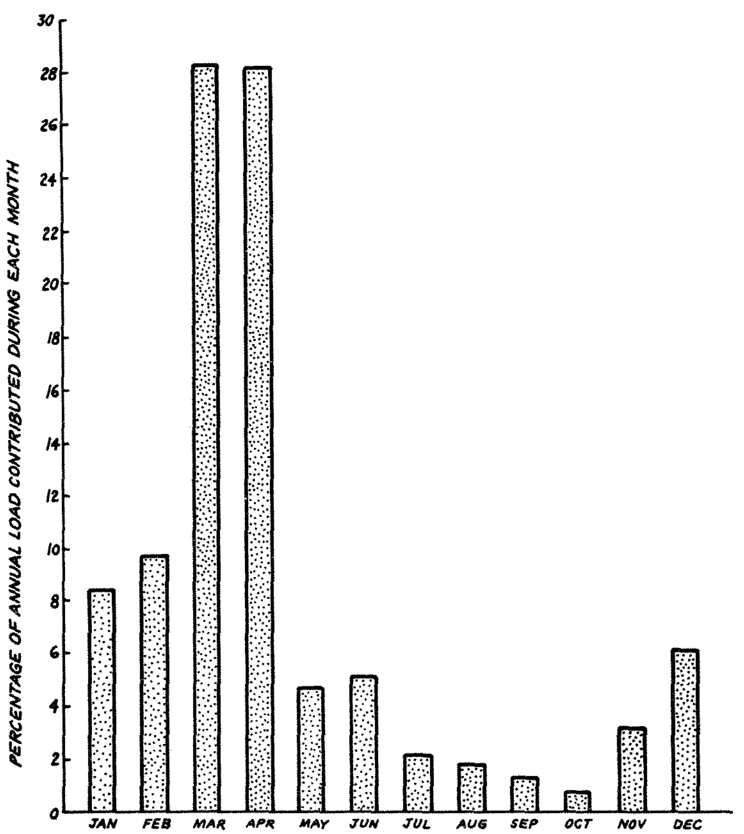

Fig. 1 Percentage of annual suspended sediment load contributed during each month of the year.

various sediment loading computational methods to various sampling frequencies of suspended sediment concentrations were explored by means of the following study stages:

(a) Three years of daily suspended sediment loading data for the Big Otter Creek were selected as a base population (Environment Canada). In addition to the daily suspended sediment loads, daily streamflow values, sampled concentration values and estimated mean daily concentrations were available.

(b) Four sampling frequencies were selected for application to the base population. These frequencies included: (i) one concentration sample per month for only the summer months of April to October, (ii) one sample per month for the year, (iii) one sample per week for the year, and (iv) one sample per week plus one sample per day when the daily flow exceeded a selected extreme value. The 3 year population was sampled 3 times at each frequency, yielding nine effective years of sampling.

(c) Five computational methods were applied to the various samples of suspended sediment concentration values in conjunction with the record of daily flow to determine estimates of annual sediment loads. Each method is identified below:

(i) *Simple equation* One approach to the estimation of annual sediment loads, which has been used and reported by Ongley (1976), involved application of the simple equation,

$$\hat{Q}_s = c\ Q \tag{1}$$

where $\hat{Q}_s$ = the estimated annual suspended sediment load, c = the mean of suspended sediment concentration samples obtained during the year, and Q = the annual streamflow.

(ii) *Linear interpolation* This computation methodology involved the relationship,

$$\hat{Q}_s = \Sigma_{i=1}^{365} c_i\ Q_i \tag{2}$$

where c_i = the estimated mean daily sediment concentration (i.e. the sampled value for a sampled day, and a linearly interpolated value between sampled values for those days when concentration was not sampled), and Q_i = the mean daily streamflow.

(iii) *Beale ratio estimator* This procedure was recommended for use in the IJC-PLUARG studies (PLUARG, 1977). It involved the subdivision of the concentration samples according to an arbitrary classification of high and low flows. High mean daily flows were assumed to be those equalled or exceeded 15% of the time. The mean of the suspended sediment concentrations sampled during days of high flow was applied to all days exhibiting a high flow; the mean of concentrations sampled during low flow days was applied to all days exhibiting a low flow. This approach, based on the notion of stratified sampling, involved only two strata.

(iv) *Single rating curve* For this method equation (2) was applied with the c_i values determined from an annual sediment concentration *vs*. streamflow rating curve developed from the sampled concentrations for each year of sampling.

(v) *Moving rating curve* This method was similar to the single rating curve in that sediment rating curves were used. However, many curves were developed for each year of sampling on the basis of small groups of successive concentration samples appropriate to the associated flow conditions. This method has also been referred to as the Integration Method (van Vliet *et al.*, 1978).

(d) The mean ratio of the estimated annual suspended sediment load to the population suspended sediment load, $\hat{Q}_S/Q_S$, was determined for each sampling frequency in conjunction with each computational method as an index of accuracy.

(e) The standard deviation of the $\hat{Q}_S/Q_S$ ratio was also computed for each sampling frequency and methodology as an index of precision.

RESULTS AND DISCUSSION

The computed indices of accuracy and precision have been summarized in Figs 2 and 3 respectively. Consideration of Figs 2 and 3 yields the following observations regarding the estimation of annual suspended loads in Big Otter Creek:

(a) Most computational methods result in an underestimation of the sediment load for the sampling frequencies analysed. Infrequent sampling of suspended sediment concentrations can lead to gross underprediction.

(b) The moving rating curve method is the most accurate and the most precise method of those tested for all but the lowest sampling frequency.

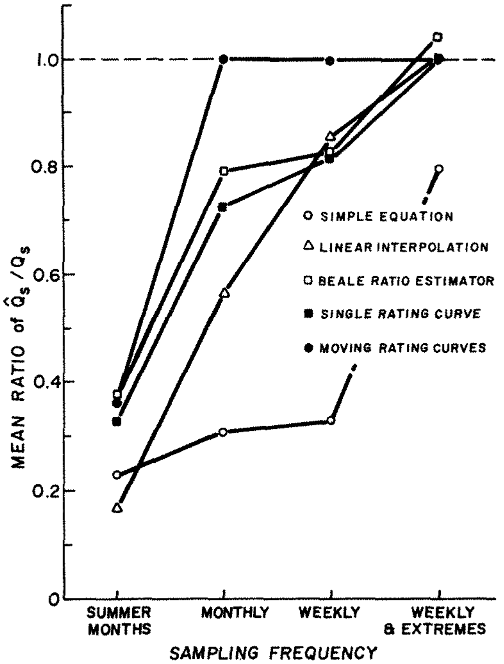

Fig. 2 Mean ratio of $\hat{Q}_s/Q_s$ computed using five methods *vs.* sampling frequency, as an index of accuracy.

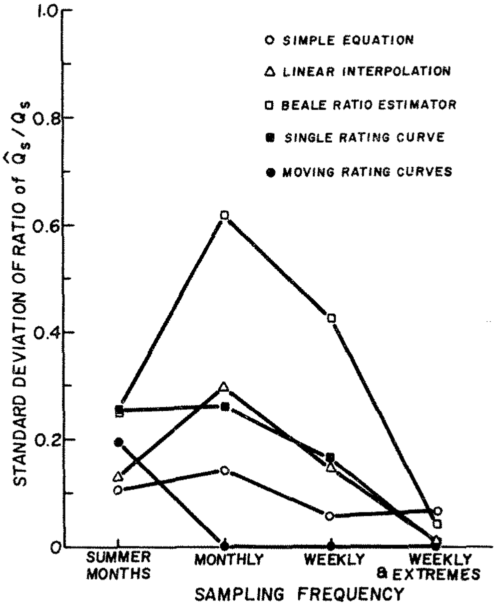

Fig. 3 Standard deviation of $\hat{Q}_s/Q_s$ computed using five methods *vs.* sampling frequency, as an index of precision.

(c) The simple annual equation is reasonably precise but very inaccurate. If the inaccuracy were found to be consistent, a simple correction factor could be applied to render the annual estimate more accurate.

(d) The Beale ratio estimator is reasonably accurate at the highest sampling frequencies, is the only method to overpredict on the average at the highest frequency, and is the least precise of the methods tested. The last observation is of particular significance when the method is applied to only 1 or 2 years of record.

(e) The linear interpolation and single rating curve methods are reasonably accurate and moderately precise at the highest sampling frequencies.

CONCLUSIONS

The results of the study reveal that for hydrological and suspended sediment regimes akin to those of Big Otter Creek, the sampling frequency of sediment concentrations and the method of computation of annual sediment loads can have significant effects on both the accuracy and precision of sediment load estimates. The relative level of accuracy for a particular computational method applied to a selected sampling frequency does not necessarily correspond to the relative level of precision for the same combination of method and frequency. Therefore, the topics of both accuracy and precision need to be considered when methodologies and sampling frequencies are being reviewed.

The accuracy and precision of annual sediment estimates can be characterized satisfactorily by relatively simple indices. These indices can serve as useful tools for the evaluation of existing data sets and for the selection of sampling schemes and computational strategies.

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